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van Beers, C.; van den Bergh, J.C.J.M.; de Moor, A.; Oosterhuis, F.H.

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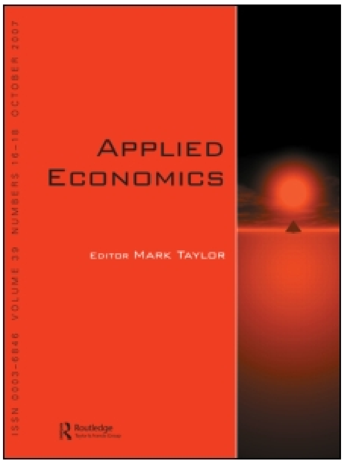

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Cees van Beers[a]; Jeroen C. J. M. van den Bergh[b]; André de Moor[c]; Frans Oosterhuis[d]
[a] Department of Economics, Delft University of Technology, Delft, The Netherlands [b] Faculty of Economics and Business Administration & Institute for Environmental Studies, Free University, Amsterdam, The Netherlands [c] National Institute for Public Health and the Environment, Bilthoven, The Netherlands [d] Institute for Environmental Studies, Free University, Amsterdam, The Netherlands

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Determining the environmental effects of indirect subsidies: integrated method and application to the Netherlands

Cees van Beers[a,*], Jeroen C. J. M. van den Bergh[b], André de Moor[c] and Frans Oosterhuis[d]

[a]*Department of Economics, Delft University of Technology, Delft, The Netherlands*
[b]*Faculty of Economics and Business Administration & Institute for Environmental Studies, Free University, Amsterdam, The Netherlands*
[c]*National Institute for Public Health and the Environment, Bilthoven, The Netherlands*
[d]*Institute for Environmental Studies, Free University, Amsterdam, The Netherlands*

The term 'environmentally damaging subsidies' covers all sorts of direct and indirect subsidies with negative consequences for the environment. This article presents a method to determine the environmental impact of these subsidies. It combines a microeconomic framework with an environmental impact module. The method is particularly useful for analysing indirect subsidies. These are often hidden, and therefore, not recognized as subsidies. Use of the method will provide a basis for formulating corrective policy. The method is applied to several important subsidies in the Netherlands, in agriculture, energy and transport sectors. The results reveal large environmental effects, which deserve serious attention from policy makers. To illustrate the specific features of the method, its application to a particular subsidy, namely the exemption of excise taxes on aviation fuels, is presented in full detail.

I. Introduction

At the World Summit on Sustainable Development in Johannesburg government leaders have re-confirmed that sustainable development should be a top priority for government policy. Research suggests that many current government policies and public structures are still subsidizing activities to such an extent that environmental externalities are magnified. Governments spend hundreds of billions of dollars to subsidize production and consumption in resource-intensive sectors like agriculture, transport, energy, water, forestry and fisheries (OECD, 1998, 1999; van Beers and de Moor, 2001). Many of these subsidies especially indirect types of support lead to unintended but significant environmental effects.

*Corresponding author. E-mail: c.p.vanbeers@tbm.tudelft.nl

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As opposed to direct subsidies, which are visible at the expenditure side of the government's budget, indirect subsidies often are not recognized as subsidies. They include various types of governmental interventions, for example, tax exemptions for particular groups, determination of minimum prices for agricultural products and financial guarantees, such as export credit facilities. A little known fact is that most subsidies are indirect. This is partly due to the fact that it is quite difficult to determine the economic and environmental consequences of these indirect subsidies, both in theory and in practice. Although applied welfare economics offers tools for the study of economic and environmental impacts of all sorts of government policies, no specific attempt has been made to address the environmental impact of indirect subsidies. Standard public economics theory analyses subsidies often as negative taxes without any specific features assigned to subsidies (Atkinson and Stiglitz, 1980).

This article uses a microeconomic framework to determine the environmental effects of indirect government subsidies in a transparent and relatively straightforward manner. The approach includes a set of models for different circumstances and subsidy types. In addition, it covers the assessment of a number of environmental effects as well as aggregation and weighting of these into an aggregate environmental index. Although the lack of government policy aimed at internalizing external effects is not considered a subsidy here, the policy framework is also suitable to analyse and calculate the environmental impact associated with such external effects. Similarly, the method can be used to determine the environmentally benign effects of subsidies specifically aimed at stimulating behavioural changes towards less environmentally damaging consumer (e.g. transport) or production patterns.

The literature on environmental impacts of subsidies consists of two types of studies. The first focus on qualitative analysis and formulation of policies to undo the negative effects of these subsidies (De Moor, 1997; van Beers and de Moor, 1997; Myers, 1998; van Beers and van den Bergh, 2001). The second type uses formal models aimed at measuring the environmental effects of subsidies. Different approaches are available. The most comprehensive of these is general equilibrium (GE) modelling, which covers direct and indirect economic effects of taxes or subsidies. Direct effects relate to changes in the sector (inputs or output) that is subsidized. Indirect effects include income effects, derived changes in related sectors and markets, and changes in demand, imports and exports. General equilibrium modelling is a 'heavy' tool which requires many assumptions regarding the behaviour of consumers and sectors, as well as about model closure. In addition, many parameters need to be estimated (see also Burniaux *et al.*, 1992; McKibbin and Wilcoxen, 1996; Anderson and McKibbin, 1997).[1] When indirect effects are less relevant or are of a known magnitude (e.g. a certain fraction of direct effects) or when subsidies are not too large, partial equilibrium analysis can provide insight into the order of magnitude of economic and environmental effects.[2]

Partial equilibrium analysis is restricted to a single sector or an incomplete set of sectors (not covering the whole economy). An example is the so-called 'Marginal Effective Tax Rate' (METR) method (MacKenzie *et al.*, 1997, 1998). It is based on the assumption of profit maximizing behaviour of firms' decisions about input and production levels, from which it derives rules about the impact of taxes and subsidies. Another partial equilibrium approach is based on combining estimates of elasticities with observed price differences. Larsen and Shah (1992) and IEA (1999) use models along these lines to estimate the potential impact of a removal of energy subsidies on the reduction of global CO_2 emissions. Both this approach and METR require less data and specific assumptions than GE modelling.

The present study is an example of the partial equilibrium approach. It extends the existing literature by providing a general microeconomic methodology to estimate the environmental effects of indirect subsidies. In contrast with, for example, IEA (1999), it allows for dealing with all possible incidence points of specific subsidies in the chain

[1] This does not mean that we dismiss CGE models as irrelevant, but simply that for the single sector effect of specific subsidies a partial equilibrium framework can provide a good (direct) approximation of the magnitude of overall (including indirect) effects. This would be less evident in the case of policies or scenarios directly affecting large parts (multiple sectors) of the entire economy, such as in the case of climate change (Kokoski and Smith, 1987).

[2] Input–output models might be considered as well, as they allow capturing interactions among sectors. A main disadvantage is, however, that they do not describe prices (and implicitly assume fixed prices), so that they cannot analyse behavioural effects due to price and cost changes. As a result, these types of models are unsuitable to assess the environmental impacts of subsidies.

of activities and markets, and is therefore applicable to a wide variety of subsidies applied to a range of economic sectors. The approach is both policy relevant and does not require too many data. Of course, elasticity estimates benefit from available, usually econometric studies.[3] Two disadvantages of this partial equilibrium approach are as follows. When indirect effects are large relative to the direct effects, the real economic and environmental effects will be under or overestimated. Moreover, like all other existing approaches, ours uses static models, so that no attention is devoted to cumulative effects, delays and technological innovation effects.

The definition of a subsidy is an important starting point for our analysis. We have used a broad definition, namely all government interventions that directly or indirectly keep the price for consumers below, or for producers above, the market price levels. A useful taxonomy of subsidies is as follows:

(1) Tax subsidies through deductions, exemptions or special tariffs such as reduced energy taxes for specific sectors or a low VAT rate on food.
(2) Public provision of goods and services below the cost such as infrastructure or associated services.
(3) Capital subsidies such as loan guarantees, debt forgiveness or government loans with lower than market interest rates or under soft conditions.
(4) Price regulation: policy measures through the market mechanism shifting the cost burden (partly) to market players; examples are minimum prices for agricultural products and maximum prices through price controls.
(5) Quantity restrictions: regulations towards a minimum use of a certain input or product; an example is the regulatory rule set by Germany that electricity companies should use a minimum quantity of domestically produced coal.
(6) Trade barriers: regulation of imports through rules, quotas and export credits.

In the next section the conceptual structure of the method is presented. Section III describes the microeconomic models that are used to translate the policy framework into an operational tool. Section IV applies the method to, and reports empirical results for, eight major indirect subsidies in the Netherlands. These relate to the production sectors agriculture, energy and transport. One subsidy is analysed step by step in order to show how the method works in detail. A final section presents conclusions.

II. The Method

Introduction

The method is based on identifying a chain from a subsidy to its environmental impact. This is captured in the following three equations:

$$q = F(P(s), T(s), D(s)) \tag{1}$$

$$z_{m,n} = H_{m,n}(I(s), T(s), q, D(s)) \quad \text{for relevant values of } m \text{ and } n \tag{2}$$

$$Z_m = \sum_n w_{m,n} z_{m,n} \quad \text{for relevant values of } m \tag{3}$$

The symbols have the following meaning:

q = output;
P = vector of production factors or inputs;
s = a subsidy or collection of subsidies;
T = technology;
D = demand;
I = infrastructure;
$z_{m,n}$ = environmental impact of effect n in general impact category m;
Z_m = general environmental impact;
F, G, $H_{m,n}$ = functional relationships;
$w_{m,n}$ = weighting factor for environmental effects.

The first equation gives a relationship between an indirect subsidy and output, using as an example a subsidy that directly affects production factors, technology and output or production level. In certain applications of this partial equilibrium framework cross-price effects (either related to substitutes or complements) occur and are relevant. Although prices are not made explicit in the framework, such effects may be taken into account when they have a relevant magnitude. The specific mechanisms and chain of effects are discussed in more detail in the section 'Economic effects of indirect subsidies'. The second equation is used to calculate specific environmental effects based on information about inputs, technology or output. The third equation calculates the overall environmental impact through weighted summation. This is based on the identification of

[3] Some studies directly combine econometric analysis with a partial equilibrium model to assess the impact of government policies like subsidies (e.g. Giosa *et al.*, 1999; Ostbye, 1998).

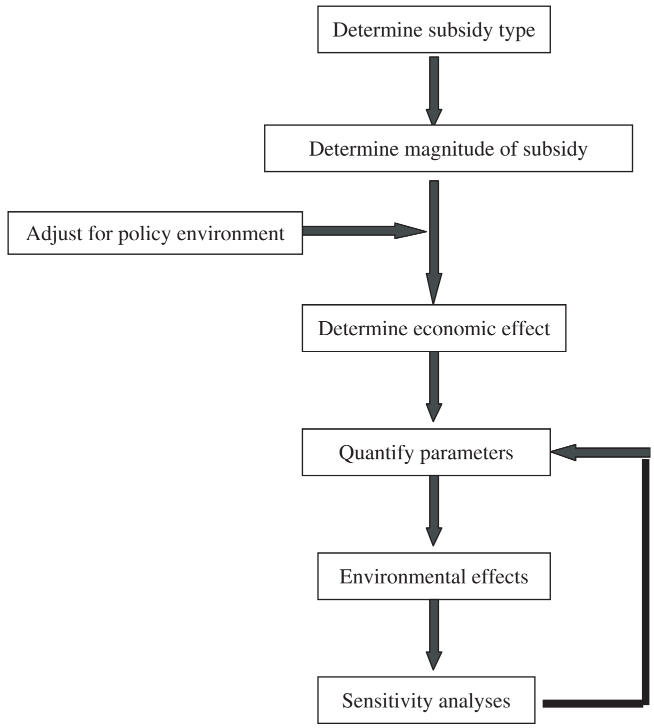

Fig. 1. Policy framework for subsidy assessment

general categories of environmental impact (e.g. global warming potential). This approach is discussed in more detail in the section 'environmental effects of indirect subsidies'. The environmental impact as modelled in (2) can apply to either environmental or pollution stocks or flows. However, for certain stock effects a more complicated specification might be needed to address threshold effects (e.g. nutrient loading in lakes). The subsidies and related sectors that we have studied do not require this type of approach. Even the modelling of the effects of CO_2 emissions can be accomplished with a flow approach (namely, global warming potential), which reflects a marginal effect of additional CO_2 emissions on global warming. Section III presents formal model expressions of the above general framework that calculate the economic and environmental impact of specific subsidies.

Economic effects of indirect subsidies

The policy framework is illustrated by the stepwise procedure depicted in Fig. 1.

First the type of subsidy is determined to identify the specific model needed for the analysis. This is followed by an assessment of the (monetary) magnitude of the subsidy, which can be regarded as a rough measure of the magnitude of the economic and environmental disturbance caused by the subsidy under consideration. The next steps are formalization and quantification of the mechanisms that determine the economic effects of the different indirect subsidies. The mechanisms differ between subsidy types and can include a number of economic variables, including supply, demand, prices, input mix and technology type. In a subsequent step, the economic effects are the inputs to the calculation of environmental impacts. The end result is a quantitative relationship between the magnitude of the subsidy on the one hand, and the generated economic and environmental effects on the other. Note that policy filters may be required to correct for the impacts of other government policies if these enhance or compensate the effects of a particular subsidy. One example is the combination of quotas and the subsidy type 'guaranteed prices', which is typical for milk, support in the agricultural sector in the Netherlands (see the section 'Minimum prices').

The magnitude of a subsidy is determined as the amount of money (prices or cost savings) or as a volume of a physical product (functional units or kg). If it is not possible to quantify the subsidy, this does not necessarily mean that the analysis of the impacts of such a subsidy will only provide qualitative information. An example is a production subsidy that stimulates use of another production technique. A comparison of the environmental effects of the different techniques is then still possible.

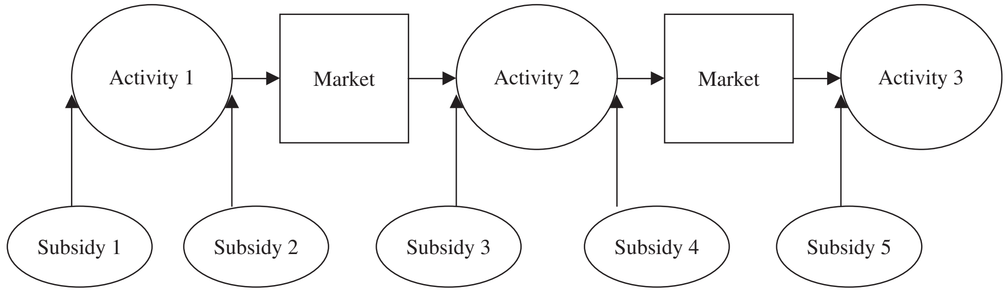

Fig. 2. Points of incidence of a subsidy in activities and markets

From a theoretical perspective, a key factor behind the impact of a subsidy on the economy is the point of incidence of the subsidy in the chain of activities and markets. This is illustrated in Fig. 2.

A chain with three activities offers a sufficiently rich framework to analyse both the flows of intermediate goods and linkages between economic activities (e.g. activity $1 \rightarrow 2$), and the final products going to consumers (e.g. activity $2 \rightarrow 3$). The activities are connected through markets, which transmit the impact of the subsidy to other economic variables. For example, producer subsidies can affect input and output prices directly and the quantities indirectly. The reaction of the prices and, hence, the effect on the quantities produced are incorporated in the price elasticity. The ultimate effect of a subsidy depends partly on the kind of competition in the relevant markets. An example is diesel tax reduction to truck drivers. The fierce competition in this sector promotes the transmission of the resulting price reduction to other sectors in the production chain. As a result, the economic activity of the transport sector hardly changes. Consumer subsidies like VAT-exemptions affect the quantities demanded through the price directly. Both an income and price effect then emerge. A tax exemption for commuting traffic, for example, increases income and reduces the costs of commuter traffic. All these examples require specific models for their analysis.

Environmental effects of indirect subsidies

In order to estimate the environmental effects of subsidies, it is necessary to consider the relationship between the economic effects as discussed earlier on the one hand and the relevant environmental effects on the other. The environmental effects can be related to the inputs or outputs. Where possible, we assume a fixed relationship between outputs and environmental effects (Equation 2). Five environmental categories are relevant in the present study (Equation 3)[4]:

(1) Enhanced greenhouse effect: this covers carbon dioxide (CO_2) emissions (relevant to both energy and transport), methane (CH_4) emissions (agriculture) and nitrous oxide (N_2O) emissions (transport and agriculture).
(2) Acidification: NO_x and SO_2 emissions are particularly relevant for the energy and transport sectors; NH_3 emissions are particularly relevant for agriculture.
(3) Photochemical creation of ozone: emissions of volatile organic compounds (VOC) and carbon monoxide (CO) occur in particular in transport. NO_x emissions are also important.
(4) Eutrophication: phosphates, nitrates, biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The phosphates and nitrates in particular are relevant in the agricultural sector.
(5) Land use: although land use is not an environmental impact indicator, its impact is important in the agricultural sector. It also plays a role in discussions about possible indicators for biodiversity.

In choosing the aforementioned effects for this study, we are focusing on the most important environmental problems as indicated in the National Environmental Policy Plan 4 of the Dutch government. The decision to limit this study to the effects on the most important environmental themes is motivated mainly for practical considerations; more indicators can easily be added in a subsequent study, such as depletion of the ozone layer, human and ecological toxicity, soil, water and groundwater pollution, noise pollution, odour nuisance, safety, waste and groundwater pumping (see VNCI, 2001).

The analysis of the environmental effects translates the economic effects – on inputs or outputs – into

[4] These categories are based on the Environmental Performance Indicators (EPI) method. See VNCI (2001).

environmental effects. This is done using various data sources and parameters, including those that were available at the National Institute for Public Health and the Environment (RIVM).

Next, the general environmental impacts of emissions in the relevant categories, Z_m, are created by multiplying each type of emission (in kg/year) in a particular category (z_{mn}) – e.g. CO_2 in the Greenhouse category – with a (unique) weighting factor. Appendix A contains an overview of the weighting factors used. The results for all the emissions within each category are then aggregated through weighted summation, which produces Z_m for that category.

Note that it is possible, in principle, for the emission of a particular substance to contribute to several z_{mn} to which different weighting factors apply. For example NO_x contributes to three categories (acidification, photochemical ozone creation and eutrophication).

Finally, a sensitivity analysis will have to be performed in which alternative values of the parameters will give insight into the reliability of the calculated effects.

III. Formal Models

The method as presented in the previous section is elaborated here in a number of specific formal models to address particular subsidy types, as shown in Table 1.

Each model presentation consists of two elements. First, a formal presentation of the model is shown. This indicates how the data have to be combined so as to derive the environmental impact. The availability of data is the main restriction on the decision whether to include more or fewer factors, and as an implication, to use a more or less complicated model structure. Second, a list of factors that together determine the environmental effect(s) of a particular subsidy is presented. This suggests which data are required to apply a specific method. Table 1 provides an overview of the determining factors per subsidy type. In two cases a distinction is made depending on data availability. Note that all approaches are based on information about marginal costs. Indeed, all subsidy types in the table affect the marginal costs of production or the marginal utility of consumption of a particular product. If this would not be the case, no behavioural effect of a subsidy and, as a result, neither economic nor environmental impacts, could be identified.

A subsidy in the form of lower input prices – dominance of the technology effect

Here, we model the effect of subsidies on the behaviour of producers. This model is an extension of the basic model – optimization of profit given a production function that describes a relationship between inputs and output – with taxes and subsidies. Although we are interested here in lower input prices due to a subsidy, the extended model can be used to study a wide range of changes that are caused by subsidies. Given the static character of the model, long-run effects of technological choices within companies, as well as the effects on a higher scale (such as sector structure, volume and composition of demand) are not captured by this partial equilibrium model.

The company maximizes profit W:

$$W = (1 - t_w)[(p + s_p)Q - C - v + d_b] + v + d_v \quad (4)$$

with production costs C

$$C = (p_K - s_K)K + p_L L + (p_I - s_I)I + (p_E - s_E)E \quad (5)$$

and production function

$$Q = F(K, L, I, E) \quad (6)$$

The symbols are:

W = profit;
C = total costs;
Q = output;
K = capital;
L = labour;
I = infrastructure;
E = energy;
p = output price;
p_K = capital price;
p_L = price of labour (wages);
p_I = price of infrastructure;
p_E = price of energy;
t_w = proportional tax on profit.

The possible subsidies are:

$Q \leq Q_{\max}$ volume regulation on output;
$p \geq p_{\min}$ price guarantee on output;
$I = I^*$, and $p_I = 0$: public supply below cost price;
s_p = subsidy on the selling price;
s_K = subsidy on capital;
s_I = subsidy on infrastructure (public provision of goods below cost price);
s_E = subsidy on energy (including exemption from regulatory energy taxes);

Table 1. Factors that determine economic and environmental effects, per subsidy type and according to availability of data

Type of subsidy	Relevant data available	Incomplete data
1. Subsidy in the form of reduced input prices	• Magnitude of subsidy • Parameters of production function • Magnitude of relevant input • Output price and input prices • Pollution intensity of production	
2. Subsidy on inputs in the form of tax measures (tax subsidies)	• Magnitude of subsidy • Price reaction in demand • Output price reaction in supply • Input price reaction in supply • Pollution intensity of production	
3. Subsidy on outputs in the form of tax measures (tax subsidies)	3a. *Production* • Magnitude of subsidy • Price reaction in demand • Price reaction in supply • Pollution intensity of production 3b. *Consumption* • Magnitude of subsidy • Demand effect of the subsidy • Pollution intensity of consumption or production of consumed product	3a. *Production* • Magnitude of subsidy • Price reaction in equilibrium • Volume • Pollution intensity of production
4. Public supply below cost price	Like case 1	
5. Capital subsidies	Formal analysis problematic	
6. Minimum prices	• Currently supplied volume • Demanded volume at free market price • Pollution intensity of production	• Supplied volume • Demanded volume at world market price • Pollution intensity of production
7. Volume regulation	Like case 6	
8a. Import barriers (trade measures)	Like case 7	
8b. Export credit guarantees (trade measures)	Formal analysis problematic	

$v =$ tax-free allowance;
$d_v =$ tax-free direct subsidy;
$d_b =$ direct subsidy (before taxes).

The subsidies $Q_{\max}$ and $p_{\min}$ lead to extra conditions in the company's optimization problem. The ideal way to determine the effect of these indirect subsidies would be to compare the relevant results of the optimization problem (output or input, depending on the point of application of the environmental effects) with and without the extra condition in question. Since this is not possible in practice, an approximation based on extrapolation of marginal effects will be developed.

Rewriting Equations 4 and 5 gives an insight into effective prices:

$$W = p^*Q - p_K^*K - p_L^*L - p_I^*I - p_E^*E + [t_w - s_w]v + (1 - t_w + s_w)d_b + d_v \qquad (7)$$

Here s_w denotes a subsidy in the form of a lower proportional tax on profits, and price symbols with an asterisk stand for

$$p^* = (1 - t_w + s_w)(p + s_p) \qquad (8)$$

$$p_K^* = (1 - t_w + s_w)(p_K - s_K) \qquad (9)$$

$$p_L^* = (1 - t_w + s_w)p_L \qquad (10)$$

$$p_I^* = (1 - t_w + s_w)(p_I - s_I) \qquad (11)$$

$$p_E^* = (1 - t_w + s_w)(p_E - s_E) \qquad (12)$$

represent the effective prices, i.e. the prices after taxes and subsidies.

Since in Equation 7 the terms that include v, d_b and d_v do not contain Q, K, L, I or E, it follows immediately that the corporate decisions that focus on increasing or decreasing the supplied output volume or the volume of demand for an input are not affected by a tax-free allowance, nor by direct general subsidies. This is because these subsidies do not occur in the marginal rules that follow from the first order conditions for the optimization problem. Obviously such indirect subsidies do affect the level of profit.

The decisions about the demand for inputs and supply of output can then be derived from the optimization problem as a function of the various subsidies. This provides the basis for the economic model. The first order conditions for the optimization problem are:

$$\frac{\partial F}{\partial x} = \frac{p_x - s_x}{p + s_p} \quad \text{for } x = K, L, I, E \tag{13}$$

If we specify the production function as a Cobb–Douglas relationship $AK^{ak}L^{al}I^{ai}E^{ae}$, and define B as $B = a_k + a_l + a_i + a_e$, then we obtain the following (output) supply and (input) demand functions:

$$Q = \left[A(p + s_p)^B (p_K - s_K)^{-ak} p_L^{-al}(p_I - s_I)^{-ai} \times (p_E - s_E)^{-ae} a_k^{ak} a_l^{al} a_i^{ai} a_e^{ae}\right]^{1/(1-B)} \tag{14}$$

$$K = \frac{Q^{1/B} a_k}{p_K - s_K}\left[\frac{p_L^{al}(p_I - s_I)^{ai}(p_E - s_E)^{ae}}{A a_l^{al} l_i^{ai} a_e^{ae}}\right]^{1/B} \tag{15}$$

with the analogous results for L, I and E.

A number of insights follow. Note first of all that effects on output and input depend on interactions between subsidies, given that there are different subsidies on the right-hand side in Equations 14 and 15. It also follows from Equations 14 and 15 that the supply (or output or volume of production) and the demand for inputs are not affected by a reduction in the proportional tax on profit (s_w). This subsidy (lower tax) does of course affect the level of profit.

Calculating the partial derivatives from the right-hand side in Equation 14 to the various subsidies gives the marginal effects of subsidies on supply.

$$\frac{\partial Q}{\partial s_p} = \frac{BQ}{[(p + s_p)(1 - B)]} \tag{16}$$

$$\frac{\partial Q}{\partial s_K} = \frac{a_k Q}{[(p_K - s_K)(1 - B)]} \tag{17}$$

$$\frac{\partial Q}{\partial s_I} = \frac{a_i Q}{[(p_I - s_I)(1 - B)]} \tag{18}$$

$$\frac{\partial Q}{\partial s_E} = \frac{a_e Q}{[(p_E - s_E)(1 - B)]} \tag{19}$$

As expected, all effects in Equations 16–19 are positive (assuming that for inputs the subsidy level is below the market price). The expressions also offer the possibility of calculating the magnitude of the effects, if the necessary data is available.

Calculating the partial derivatives from the right-hand side in Equation 15 to the various subsidies gives the marginal effects of subsidies on the demand for inputs:

$$\frac{\partial K}{\partial s_p} = \frac{K}{[(p + s_p)(1 - B)]} \tag{20}$$

$$\frac{\partial K}{\partial s_K} = \frac{a_k K}{[(p_K - s_K)B(1 - B)]} + \frac{K}{P_K - s_K} \tag{21}$$

$$\frac{\partial K}{\partial s_I} = \frac{-a_i K}{[(p_I - s_I)B(1 - B)]} - \left(\frac{a_i}{B}\right)(P_I - s_I)^{(ai-B)/B} \times \left[\frac{p_L^{al}(p_E - s_E)^{ae}}{A a_l^{al} a_i^{ai} a_e^{ae}}\right]^{1/B} \tag{22}$$

$$\frac{\partial K}{\partial s_E} = \frac{-a_e K}{[(p_E - s_E)B(1 - B)]} - \left(\frac{a_e}{B}\right)(P_E - s_E)^{(ae-B)/B} \times \left[\frac{p_L^{al}(p_I - s_I)^{ai}}{A a_l^{al} a_i^{ai} a_e^{ae}}\right]^{1/B} \tag{23}$$

Analogous derivatives can be determined for I and E (and also L if it can be directly linked to environmental effects, which is not obvious). The signs of the effects in Equations 20 and 21 are positive, which is as expected. The signs in Equations 22 and 23 are negative, which is also as expected because price cross-effects are negative in normal practice with inputs that can be substituted (as is assumed with the choice of the Cobb–Douglas production function).

It is now possible to determine the extent of the effect of the subsidy. This depends on five variables:

- The magnitude of the subsidy (s_j for $j = p$, K, I or E).
- The production function parameters (A; a_j for $j = k$, i or e; and B).
- The magnitude of the relevant input (K, I or E).
- The output price and the input prices (p and p_j for $j = p$, K, I or E).
- The effect of the relevant inputs and output on the environmental impact (see Equation 2).

A subsidy on inputs in the form of tax measures – dominance of factor market effect

When specific information about production functions is not available, the analysis has to take place at the level of demand and supply functions. This is the point of departure of the following two approaches. They are based on interaction between final demand and supply of a particular product, which introduces demand effects in the analysis. Partial equilibrium analyses show the effects of an indirect subsidy, such as a tax-free allowance, on prices and volumes of output and input. The prices are determined by the interaction between demand and supply. Two types of tax-free allowances are considered, namely on the output price and on the input price.

We start by defining demand and supply functions in Equations 24 and 25:

$$q_d = D(p^*, p_i, y) \tag{24}$$

We assume that a tax-free allowance – i.e. an indirect subsidy s – applies to the respective product, so that $p^* = p - s$, where p is the price to which the subsidy is applied. The following conditions hold:

$D_{p^*} < 0$; $D_y > 0$; $D_{pi} < 0$ (complementary goods), or $D_{pi} > 0$ (substitutes).

$$q_s = S(p, w_i) \tag{25}$$

where:

$$S_p > 0; \quad S_{w_i} < 0$$

The symbols stand for:

q = equilibrium volume;
q_d = volume of demand;
q_s = volume of supply;
p = price of the product to be subsidized;
s = subsidy in the form of a low rate of VAT;
p^* = effective price of the product (including subsidy);
p_i = prices of other complementary or substitutable products;
y = aggregated income of the consumers;
w = input price.

The equilibrium condition is:

$$q = q_d = q_s \tag{26}$$

which is equivalent to

$$D(p - s, p_i, y) = S(p, w_i) \tag{27}$$

A subsidy s on the input price w leads to:

$$D(p, p_i, y) = S(p, w^*) \tag{28}$$

where $w^* = w - s$. Combining the total differential and obvious price changes, it then follows that:

$$D_p \mathrm{d}p - S_p \mathrm{d}p + S_{w^*} \mathrm{d}s = 0 \tag{29}$$

This can be rewritten as:

$$\frac{\mathrm{d}p}{\mathrm{d}s} = \frac{S_{w^*}}{S_p - D_p} \tag{30}$$

The effect of the subsidy on the equilibrium volume is then:

$$\frac{\mathrm{d}q}{\mathrm{d}s} = \frac{\mathrm{d}q}{\mathrm{d}p}\frac{\mathrm{d}p}{\mathrm{d}s} = \frac{D_p S_{w^*}}{S_p - D_p} \tag{31}$$

This gives the following marginal environmental effect due to a marginal change in the subsidy:

$$\frac{\mathrm{d}z}{\mathrm{d}s} = \frac{\mathrm{d}z}{\mathrm{d}q}\frac{\mathrm{d}q}{\mathrm{d}s} = Z_q\left(\frac{D_p S_{w^*}}{S_p - D_p}\right) \tag{32}$$

If the magnitude of the subsidy is equal to Δs, then the environmental effect is equal to:

$$\Delta z = Z_q\left(\frac{D_p S_{w^*}}{S_p - D_p}\right)\Delta s \tag{33}$$

The sign of this is positive. In other words, a given change in a tax-free allowance for an input factor to a polluting production process results in greater environmental damage. The extent of that damage depends on five variables[5]:

- The magnitude of the subsidy (Δs);
- The price reaction in the demand (D_p);
- The output price reaction in the supply (S_p);
- The input price reaction in the supply (S_{w^*});
- The pollution intensity of production (Z_q).

Finally, note that it is assumed that the market price w of the input is not affected by the subsidy. If it were affected, then a more complicated expression than Equation 33 would result and additional information would be needed.

A subsidy on output in the form of tax measures – dominance of market effect

Production. We start immediately with the equilibrium condition in Equation 27. In order to find the effect on the equilibrium price, the equilibrium volume and the external effect, the total differential is determined:

$$\begin{aligned} &D_{p*}(\mathrm{d}p - \mathrm{d}s) + D_{p_i}\mathrm{d}p_i + D_y\mathrm{d}y - S_p\mathrm{d}p \\ &\quad - S_s\mathrm{d}s - S_{w_i}\mathrm{d}w_i = 0 \end{aligned} \tag{34}$$

The subsidy has an effect on the equilibrium price and the equilibrium volume. We can therefore suppose that $\mathrm{d}p_i = \mathrm{d}y = \mathrm{d}w_i = 0$, which leads to:

$$D_{p*}(\mathrm{d}p - \mathrm{d}s) - S_p \mathrm{d}p = 0 \tag{35}$$

[5] Price reaction of demand (or supply)' means: the absolute change in the demanded (supplied) volume that occurs in reaction to a given price change. 'Price elasticity of the equilibrium volume' means: the relative change in the demanded volume (with respect to the equilibrium state) as a result of a relative price change of 1%.

It then follows that:

$$\frac{\mathrm{d}p}{\mathrm{d}s} = \frac{D_{p*}}{D_{p*} - S_p} \tag{36}$$

Here, we are mainly interested in the effect of the subsidy on the equilibrium volume since that is the point of application for environmental effects in this model. This effect can be determined as follows:

$$\frac{\mathrm{d}q}{\mathrm{d}s} = \frac{\mathrm{d}q}{\mathrm{d}p^*}\frac{\mathrm{d}p^*}{\mathrm{d}s} = D_{p*}\left(\frac{\mathrm{d}p}{\mathrm{d}s} - 1\right) = \frac{D_{p*}S_p}{D_{p*} - S_p} \tag{37}$$

Note that the sign here is positive. This means that a higher subsidy (lower VAT) stimulates consumption and thereby production of the product in question.

We next assume a positive dependence of an environmental effect z on the produced equilibrium volume, such that:

$$z = Z(q) \tag{38}$$

with

$$Z_q > 0$$

From Equations 37 and 38 it can be derived that the environmental effect of the subsidy is equal to:

$$\frac{\mathrm{d}z}{\mathrm{d}s} = \frac{\mathrm{d}z}{\mathrm{d}q}\frac{\mathrm{d}q}{\mathrm{d}s} = Z_q\frac{D_{p*}S_p}{D_{p*} - S_p} \tag{39}$$

The effect in Equation 39 is a marginal effect that can be considered the average effect for relatively small changes. In other words, if the magnitude of the subsidy is Δs, then the environmental effect is equal to:

$$\Delta z = Z_q\frac{D_{p*}S_p}{D_{p*} - S_p}\Delta s \tag{40}$$

The sign here is positive, i.e. the effect of the subsidy (a low rate of VAT) on the environmental impact of production is positive. The environmental impact of the subsidy thus depends on four variables:

- The magnitude of the subsidy (Δs);
- The price reaction in the demand (D_{p*});
- The price reaction in the supply (S_p);
- The pollution intensity of production (Z_q).

The second variable in this list depends on the type of product (e.g. necessity or luxury) and on consumers' preferences. The third element reflects the production costs of the company (or sector), and indirectly also substitution possibilities in the input mix, availability of alternative production techniques, and the competitive situation on the sales market.

Note that Equation 40 can also be expressed in terms of price elasticities of demand and supply. Most price elasticities already include the interaction between demand and supply. In this case a more simple equation can be used:

$$\Delta z = \left(\frac{Z_q e_{p*} q^*}{p^*}\right)\Delta s \tag{41}$$

where e_p is the price elasticity of the equilibrium volume. The environmental impact of the subsidy then depends on four variables:

- The magnitude of the subsidy (Δs);
- The price elasticity of the equilibrium volume (e_{p*});
- The equilibrium volume and price (q^* and p^*);
- The degree of pollution from production (Z_q).

If separate information is not available about supply and demand, Equation 41 provides an adequate approach to calculate the environmental effects.

Effect of subsidies on consumer decisions. A model is presented here that reflects the effect of subsidies on consumer decisions. Consumer subsidies are to be expected in particular in the transport and tourism sectors. Think of the flat-rate allowance for travel costs or the exemption from VAT on airline tickets, for example. As with the model for producers' decisions, we will first consider the general problem and then a specific example using functional specifications of the utility function.

The consumer maximizes utility subject to the parameter condition of his budget. In general terms, the utility function can be expressed as follows:

$$U = U(x_1, \ldots, x_k, \ldots, x_n) \tag{42}$$

The budget restriction is as follows:

$$(1 - t_y)(y - f) = \sum_{i=1}^{n}(p_i - s_i)x_i \tag{43}$$

With:

U = utility;
y = income;
t_y = income tax;
f = subsidy via a flat-rate allowance;
x_i = consumption of product i ($i = 1, \ldots, n$);
p_i = price of product i;
s_i = price subsidy on product i.

Elaboration of this maximization problem yields the following demand functions:

$$x_i = D_i(p_1 - s_1, \ldots, p_k - s_k, \ldots, p_n - s_n, y, f, t_y) \tag{44}$$

with:

$$\frac{\partial x_i}{\partial y} > 0$$
$$\frac{\partial x_i}{\partial f} > 0 \tag{45}$$
$$\frac{\partial x_i}{\partial t_y} < 0$$

Let us suppose that not all goods are subject to a subsidy: $s_i = 1$ for $i = k$ and $s_i = 0$ for $i \neq k$. In the case of substitution between the goods the following applies:

$$\frac{\partial x_i}{\partial s_k} > 0 \quad \text{for } i = k \tag{46a}$$

$$\frac{\partial x_i}{\partial s_k} < 0 \quad \text{for } i \neq k \tag{46b}$$

In the case of complementary goods the following applies:

$$\frac{\partial x_i}{\partial s_k} > 0 \quad \text{for all } i \tag{47}$$

We work this out by specifying a Cobb–Douglas production function for two products, such as public transport (x_1) and subsidized private use of cars (x_2). The utility function is:

$$U = x_1^{a_1} x_2^{a_2} \tag{48}$$

This function is maximized under the parameter condition of the budget restriction:

$$(1 - t_y)(y - f) = p_1 x_1 + (p_2 - s_2)x_2 \tag{49}$$

Solving this system gives the demand functions for x_1 and x_2:

$$x_1 = \frac{a_1(1 - t_y)(y - f)}{(a_1 + a_2)p_1} \tag{50a}$$

$$x_2 = \frac{a_2(1 - t_y)(y - f)y}{(a_1 + a_2)(p_2 - s_2)} \tag{50b}$$

Differentiating to s_2 only affects the demand for the 'own' product, x_2. A larger subsidy leads to a larger demand for the product on which the subsidy is given, as is shown by the following partial derivative:

$$\frac{\partial x_2}{\partial s_2} = \frac{a_2(a_1 + a_2)(1 - t_y)(y - f)}{\{(a_1 + a_2)(p_2 - s_2)\}^2} > 0 \tag{51}$$

Differentiating to the flat-rate allowance f affects the demand for both products:

$$\frac{\partial x_1}{\partial f} = \frac{a_1(t_y + 1)}{(a_1 + a_2)p_1} > 0 \tag{52a}$$

$$\frac{\partial x_2}{\partial f} = \frac{a_2(t_y + 1)}{\{(a_1 + a_2)(p_2 - s_2)\}^2} \tag{52b}$$

The Cobb–Douglas specification implies that the cross-elasticities are zero. In transport, for example, low values for such elasticities can be substantiated based on the fact that the transfer from private to public transport is difficult due to lock-in effects.

The connection with the environmental impact is made via Equation 2:

$$\Delta z = \frac{\Delta s \partial x_i}{\partial s_k Z_q} \tag{53}$$

The extent to which tax affects the environmental depends on the following variables:

- The magnitude of the subsidy (Δs);
- The effect of the subsidy on demand ($\partial x_i/\partial s_k$). This effect depends on the assumed functional specification of the utility function. Here there is a choice between various equations. It is also possible for a subsidy to produce cross-effects. In that case the effects should be added together. However, in practice this is of limited relevance since the cross-effects are relatively small compared to the 'own' effects.
- The degree of pollution from use or production of the consumed product to which the subsidy applies (Z_q).

Public supply below cost price

This amounts to determining the effect of a reduction in the input price and involves using the approach described in the subsections Production or 'Effect of subsidies on consumer decisions'.

Capital subsidies

It is very difficult to quantify the economic effects, and consequently the environmental effects, of capital subsidies. This is because these subsidies change the conditions under which companies take decisions about investments. The specific expertise and information on such effects may well be available in the field of corporate financing, but a more detailed analysis is outside the scope of this study. Only in specific cases it is possible to carry out an analysis using a different approach. For example, in the case of low return on a government share in an airport the indirect subsidy is in the form of low airport taxes, which allows carrying out an analysis as presented in the subsection 'Effect of subsidies on consumer decisions'.

Minimum prices

As shown in Fig. 3, a producer reacts to a minimum price $p_g > p_e$ (=market equilibrium price) by producing more and offering more of the product for sale than the equilibrium volume (q_e). Consumers on the other hand reduce the volume of demand for the product because the price is higher. This creates a surplus that is accompanied by an extra subsidy transfer compared with the situation where q_e is offered for sale at price p_g. The total subsidy transfer is cdp_gp_e.

The environmental effect of the price guarantee is expressed as follows:

$$\Delta z = (q_g^s - q_e)Z_q \tag{54}$$

The volume effect (first part of the term on the right-hand side) can be derived from Equation 54. The following information is required to apply this equation:

- Supply with price guarantee, i.e. in the current situation (q_g^s);
- Supply at free market price (q_e). This requires hypothetical data, which in some cases can be based on earlier studies (e.g. with CGE models). Note that if the applicable world market price (p_w) is not equal to the domestic free market price (p_e), the supplied volume q_e in the equation should be replaced by q_w;
- The degree of pollution from production (Z_q).

Volume regulation

Since volume regulation and minimum prices usually go together, the method as described in the subsection 'Minimum prices' is relevant.

Trade measures: import barriers

The same applies here as in the section 'Volume regulation' since import barriers are a special type of volume regulation.

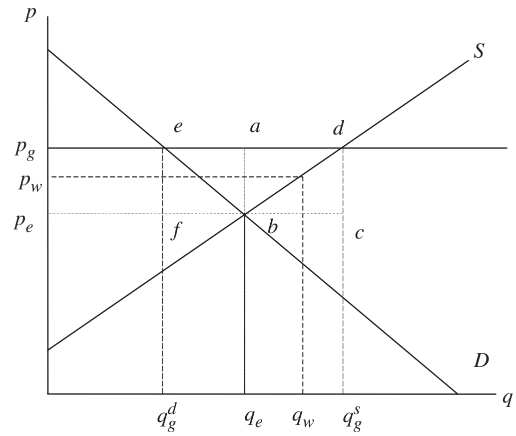

Fig. 3. The economic effect of minimum prices
q_i = volume of the product (volume of supply or demand); p_i = price of the product; D = demand curve; S = supply curve (marginal private costs).

IV. Empirical Application of the Models

General

The method of the previous section has been applied to a variety of indirect subsidies within the sectors agriculture, energy production, and transport (van Beers *et al.*, 2002). In making a selection of cases, a balanced distribution was aimed for in terms of subsidy types, subsidy size, the expected impact on producing and consuming activities, and the expected order of magnitude of the environmental impact.

In the application to agriculture, two producer subsidies were chosen (minimum prices for milk/dairy and the designation of agricultural land in land use planning) and one consumer subsidy (low VAT rate on meat). In the application to the energy sector, the exemption from the energy tax (REB) for large users was selected (a producer subsidy). In the application to transport sector, the exemption from excise tax for aviation fuels (worked out in detail subsequently), tax deduction for use of public transport in commuter traffic, incomplete coverage of rail infrastructure costs and low profitability of the government's share in Schiphol airport were analysed.

The applications show that sizable indirect subsidies can bring about relatively large environmental impacts (Table 2). This is particularly true for the subsidies given through the energy tax, milk price support and designation of agricultural land, which all interfere in an early stage in the production–consumption chain. The excise tax exemption for aviation fuels also has a substantial environmental impact. In these cases the values of the elasticities of demand play an important role. More limited environmental effects were found for the other subsidies.

The final row of Table 2 presents some information on policy goals, which serves as a benchmark for judging the magnitude of the various environmental impacts of subsidies listed in the table. It shows, for instance, that the small sample of subsidies considered here contributes to the emission of greenhouse gases to an extent equal to approximately 30% of the required reduction, and to the emission of acidifying

Table 2. Application of the method: environmental impact of eight indirect subsidies

		Environmental impact				
Cases	Amount involved (€ million per year)	Greenhouse effect (kilotonne CO_2 equivalent)	Acidification (tonne SO_2 equivalent)	Photochemical ozone creation (tonne ethylene equivalent)	Eutrophication (tonne phosphate equivalent)	Land use (hectares)
1. Minimum price milk/dairy[a]	1400	1563	17 200	300	14 500	115 000
2. Low VAT rate on meat	336	116	1703	18	1239	1400
3. Designation of agricultural land in land use planning	800	1958	21 263	346	17 951	217 800
4. Energy tax reduction/ exemption for large users	1568	811	19 728	n.a.	n.a.	n.a.
5. Incomplete coverage of rail infrastructure costs	2000	358	550	56	21	n.a.
6. Tax deduction for use of public transport in commuter traffic	147	29	70	5	11	n.a.
7. Exemption from excise tax for aviation fuels	1200	1272	2433	208	695	n.a.
8. Low profitability of government's share in Schiphol airport	80	55	106	9	30	n.a.
Benchmark: Dutch environmental policy goals for the Dutch economy as a whole, for 2010[b]		A reduction of 20 000 vs. 1990/1995	A reduction of 192 000 vs. 2000	A reduction of 108 000 vs. 2000 (total VOC emissions)	n.a. (in 2002, N and P emissions from agriculture amounted to a total of 210 000 tonne phosphate equivalents)	n.a. (in 2003 agriculture used 2.3 million hectares)

Notes: [a]Price support milk has been computed as the effect of a minimum price excluding the effects of Dutch milk quota. Including the quota would reduce the environmental effects.
[b]*Source*: RIVM (2004).
Some effects are averages based on ranges of outcomes under several variants (Price support milk, and Tax break for major energy users).
n.a. = not applicable.

emissions to an extent equal to even 46% of the required reduction, in the Netherlands in 2002.

An excise exemption on aviation fuel

Theoretical background. We illustrate the general approach by presenting the details of an analysis of the environmental impact of one particular subsidy, namely the exemption from excise tax for aviation fuels. If the size of the subsidy is equal to Δs, the environmental effect is described by Equation 33:

$$\Delta z = Z_q \left(\frac{D_p S_{w*}}{S_p - D_p} \right) \Delta s \tag{33}$$

where

- Δz = the environmental change;
- Δs = the magnitude of the subsidy (assuming that the subsidy is introduced);
- D_p = price reaction of demand for air travel ($D_p < 0$);
- S_p = output price reaction of supply of air travel ($S_p > 0$);
- S_{w*} = input price reaction of supply of air travel ($S_{w*} < 0$);
- Z_q = the pollution intensity of production ($Z_q > 0$).

The sign of the right-hand expression in Equation 33 is positive. In other words, a given change in a tax-free allowance for an input factor to a polluting production process results in greater environmental change. Equation 33 shows that the environmental effect relates to four variables: the magnitude of the input subsidy, the price reaction of demand for air traffic, the output price reaction of supply of air traffic and the input price reaction of supply, i.e. the impact of the kerosene price on air traffic supply.

As there were no specific data on the price reactions of demand and supply, we have assumed that empirical price elasticities already incorporate the interaction between demand and supply. Additionally, we assume that the kerosene subsidy directly affects the output price by the share of fuel costs in total costs. The equation then becomes:

$$\Delta z = Z_q \frac{dq}{ds} = Z_q \alpha \varepsilon_p \frac{q}{w^*} \Delta s \tag{55}$$

with:

- α = extent to which total production costs are made up of fuel costs (or extent to which the price of a ticket, which is assumed to be equivalent here, is determined by fuel costs);
- ε_p = price elasticity of demand (measured as an absolute value);
- q = extent of air traffic activity;
- w^* = price of aviation fuel (lowered with subsidy).

The environmental effects of the excise duty exemption on kerosene have been calculated by assigning the parameter values in Equation 55 step-by-step.

Extent of environmental effects per unit of activity (Z_q). The environmental effects of aviation depend greatly on the type of aircraft (engine), the distance flown, the altitude at which the aircraft flies and the capacity utilization. Dings *et al* (2002) presents emission data for four combinations of aircraft types and flown distances (Table 3).

It is now possible, assuming average capacity utilization for the four aircraft types, to estimate the emissions per passenger-kilometre (Table 4).

In order to clarify the results of Table 4, we calculate explicitly the NO_x-emission from aircraft type 2. For the LTO cycle 730 kg fuel is used causing NO_x-emission of $10\,g \times 730\,kg = 7300\,g$; in the cruise phase of the flight 2.1 kg of fuel per km is used, which gives a total of $2.1 \times 500\,km = 1050\,kg$ fuel use. The resulting NO_x-emission is $9 \times 1050 = 9450\,g$; total NO_x-emissions are: $7300 + 9450 = 16\,750\,g$; at a capacity utilization of 65% the number of passenger-kilometres is: $0.65 \times 100 \times 500 = 32\,500$; the NO_x-emission per passenger-kilometre is therefore $16\,750/32\,500 = 0.515\,g$ (=515 mg).

Extent to which total production costs are made up of fuel costs (α). At prices of the year 2000 approximately 10% of total operating costs of aviation are made up of fuel costs (Hof *et al.*, 2001). Assuming that fuel costs are fully passed on in ticket prices an increase of 1% in fuel costs would therefore lead to an increase of at most 0.1% of the ticket price.[6] We do not take into account the possibility that the proportion of the ticket price

[6] In reality, the increase in the ticket price might be slightly smaller because in addition to operating costs the ticket price covers overhead costs, profit margins, travel agency costs, etc. The assumption to pass on fuel costs fully to ticket prices is realistic as long as the share of fuel costs is not a dominant part of the operating costs. Ten per cent is not considered to be dominant. Only when fuel costs would continue to rise and hence operating costs would make up a larger part of prices, it would be recommendable to assume that fuel costs are not fully passed on to ticket prices with, for example, 50%.

Table 3. Emissions from different types of aircraft over various flown distances

			Fuel consumption		Emissions (per kg of fuel)				
Type*	Number of seats	Distance flown (km)	kg/LTO**	kg/km in cruise phase	CO_2 (kg)	SO_2 (kg)	NO_x (g) LTO	NO_x (g) cruise	VOC (g) LTO
1	40	200	130	1.0	3.15	0.6	8	7	5
2	100	500	730	2.1	3.15	0.6	10	9	2
3	200	1500	1500	5.1	3.15	0.6	14	12	1
4	400	6000	3100	11	3.15	0.6	18	15	1

Notes: *Dings *et al*. (2002) do not specify the aircraft type as regards make, number of engines, etc.
**LTO: Landing and Take Off Cycle.

Table 4. Emissions per passenger-kilometre from various types of aircraft

Type	Capacity utilization (%)*	CO_2 (g)	SO_2 (mg)	NO_x (mg)	VOC (mg)
1	50	260	50	610	163
2	65	173	33	515	45
3	70	137	26	537	7
4	80	113	22	545	2

Note: *Based on Dings *et al*. (2002).

Table 5. Estimation of the number of passenger-kilometres for air travellers leaving the Netherlands

Destination	Number of travellers	Average distance (km)	Millions of passenger-km
Europe	14 102 546	800	11 282
North Africa	335 597	2500	839
Rest of Africa	495 961	5000	2480
North America	2 571 575	6000	15 429
Rest of America	772 467	8000	6180
Western Asia	678 220	3000	2035
Rest of Asia	1 474 031	8000	11 792
Oceania	9887	16 000	158
Total	20 440 284		50 195

Source: Calculated from Netherlands statistics data; average distances are own estimates.

due to fuel costs is higher for long distances than for short distances.

Price elasticity of demand (ε_p). Brons *et al*. (2001) used an extensive database of 37 studies with 204 data entries for calculating price elasticities of demand for air travel. The values that came out with the highest frequency scores were −0.8 for business flights and −1.4 for tourist flights. As nonbusiness flights are 60% of all flights we consider −1.2 as a good estimate for ε_p.

Extent of activity (q). In 2001 more than 20 million passengers took flights out of the Netherlands. This is equal to the number of passenger-kilometres that is estimated by multiplying the numbers of passengers per regional destination (second column in Table 5) by an estimated average distance to each of these regions (third column of Table 5). The average distance can be refined by using actual distances of flights to the destinations. The result is more than 50 billion passenger-kilometres (see Table 5).

Input price (w*). In the 1980s and 1990s the real price of kerosene fluctuated between €0.10 and €0.45 per litre. We use €0.20 per litre.

Size of the subsidy (Δs)

Aviation fuels fall under CN codes 2710 00 51 and 2710 00 55 (light heavy oil) and therefore should normally be subject to the same excise duty as diesel fuel. In 2002 the standard rate of excise duty on diesel in the Netherlands was €0.33 per litre. To the extent that aviation fuels remain untaxed, this rate can be considered to be equal to the amount of subsidy per litre. In the Netherlands 3.2 billion kg of aviation fuel was supplied exempt from excise duty (source: Netherlands Statistics). Assuming a density of 0.85 kg/l leads to a total amount of subsidy of €1.2 billion/year.

Calculating the economic and environmental effects. Using Equation 55, the economic effects, i.e. the change in the quantity of air travel due to the subsidy, can be calculated as follows:

$$\frac{dq}{ds} = \alpha \cdot \varepsilon_p \cdot \frac{q}{w^*} \cdot \Delta s = 0.1 \cdot (1.2) \cdot \frac{50.10^9}{0.20} \cdot 0.33 = 9.9 \cdot 10^9$$

The result shows that the exemption leads to an increase of annual passenger kilometres by plane equal to 9.9 billion kilometres. This is 20% of the total number of annual passenger kilometres.

The environmental effects can now be estimated by combining the information on the number of passenger kilometres (Table 5) with the information on the emissions (Table 4). The results are reported in Table 6. In order to clarify these results we calculate the NO_x-emission from aircraft type 2 for flights to European destinations: NO_x emission per passenger-kilometre flows by aircraft 2 is 0.515 g; the number of passenger-kilometres (11 282 million) is 20% higher than in a world with excised duties on kerosene. Hence 2234 million passenger-kilometres are caused by the exemption. This leads to an estimate of NO_x-emissions equal to $0.000515 \times 2234 = 1.15051$ million kg = 1151 ton.

The final step is aggregating the environmental effects to the four pollution categories as defined in Appendix A. These are reported in Table 7. The environmental effects are 1.3 megatonne CO_2-equivalents and 2.4 kilotonne SO_2-equivalents (based on parameters chosen).

Sensitivity analysis. The method is based on linear relationships. Therefore, a change of parameters will have a proportional effect on the environmental impact. For example, if the price elasticity takes values of −0.4 and −2.7, which are the most extreme values in ranges reported by Oum *et al*. (1990), the environmental effects will be 2/3 lower and more than 2 times higher, respectively than the numbers reported in Tables 6 and 7.

Conclusion of the case study. Fuel for international air traffic is exempt from excise duty. This is based on international treaties as well as national and EU regulations. This exemption is a subsidy as it means lower costs for the aviation sector. In particular, it is a subsidy on an input of a production activity. For the Netherlands the size of this subsidy amounts to approximately €1.2 billion/year. The subsidy provokes an estimated 20% more passenger kilometres. The important environment impacts are the greenhouse effect, acidification, photochemical ozone creation and eutrophication.

Since artificially low aviation fuel prices may cause a break on technological innovation of aviation engines as well as provide a weak incentive to utilize air planes up to their full capacity, the estimates of

Table 7. Environmental indicators for exemption of excise duties on aviation fuel in the Netherlands

Pollution category	Emissions
Greenhouse effect (ktonnes of CO_2-equivalents)	1272
Acidification (tonnes SO_2-equivalents)	2433
Photochemical ozone creation (tonnes ethylene-equivalents)	208
Eutrophication (tonnes phosphate-equivalents)	695

Table 6. Estimation of the environmental effect of subsidizing aviation fuel for flights leaving the Netherlands

Regional destination	Aircraft type	CO_2 (ktonnes)	SO_2 (tonnes)	NO_x (tonnes)	VOC (tonnes)
Europe	2	385	73	1151	100
North Africa	3	23	4	89	1
Rest of Africa	4	56	11	267	1
North America	4	346	66	1664	5
Rest of America	4	139	26	666	2
Western Asia	3	55	11	216	3
Rest of Asia	4	265	50	1272	4
Oceania	4	4	1	17	0
Total		1272	242	5344	116

the environmental impacts offered here should be regarded as lower bounds.

V. Conclusions

We have presented a method to assess the environmental (and economic) impact of indirect subsidies. The method allows to examine the magnitude and environmental effects of indirect subsidies, as behavioural responses are central to the analysis. In addition, the method is transparent in the sense that the influence of changes in parameter values can be easily traced. All these features make the method useful for policy analysis, both *ex ante* (preparation of policy) and *ex post* (evaluation of policy). More costly and laborious, multi-sector GE models can be used if it is suspected that indirect effects are significant.

A number of subsidies in the agricultural, energy and transport and tourism sectors have been analysed to illustrate and test the method. These sectors contain subsidies that are suspected to have very distortionary effects on the economy and to create sizeable environmental effects. Results of an application of the method were presented for eight different subsidies. The application of the method to one subsidy, namely the exemption of excise taxes on aviation fuels, was presented in full detail.

The applications show that sizable indirect subsidies can bring about relatively large environmental impacts (as summarized in Table 2). This is particularly true for the subsidies provided through the designation of agricultural land, exemption from the energy tax and milk price support. These subsidies interfere at an early stage in the production–consumption chain, allowing the impact to be strongly felt, in a prolonged way. The excise tax exemption for aviation fuels also has a substantial environmental impact. In all cases the sensitivity of demand for price plays an important role.

Comparison of the results with environmental policy goals shows that if the small set of eight subsidies considered here would not exist, already 30% of the required reduction in greenhouse gases, and 46% of the required reduction in acidifying emissions in the Netherlands in 2002, would have been achieved. This should be an incentive for policy makers to seriously consider removing various indirect subsidies, particularly in the areas of agriculture, energy and transport.

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Appendix A. Weighting Factors used to Calculate Environmental Indicators

Table A1 contains the weighting factors that are used to calculate environmental indicators. These factors are based on VNCI (2001).

Table A1. Weighting factors for calculating environmental indicators

Category *m* / Effect *n*	Greenhouse effect	Acidification	Photochemical ozone creation	Eutrophication
CO_2	1			
N_2O	310			
CH_4	21		0.006	
NO_x (as NO_2)		0.41	0.028	0.13
SO_2		1		
NH_3		1.30		0.35
VOC			0.5*	
CO			0.027	
Phosphate				1
Nitrate				0.1

Notes: *There is no general rule for the composition of (aggregated) VOC emissions, as the composition differs from case to case. The weighting factor of 0.5 reflects an average of the weighting factors encountered for VOCs Emissions in the EPI method. These cover the range of 0.1 to 1.0 (the reference substance with a weighting factor of 1.0 is ethylene).